FINAL REPORT

EXPLOSIVE SIZING OF 70-INCH DIAMETER WELDED ALUMINUM PREFORMS FROM 5086, 2014 T4 AND 2014 T6 MATERIAL

Prepared for

NATIONAL AERONAUTICS and SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

RYAN AEROSPACE

Report No. 62B057
16 April 1962

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I. INTRODUCTION

One portion of this Contract (NAS-8-2528) is an extension of Contract NAS-8-851, issued to Ryan to continue explosive sizing of 70-inch diameter bulkheads fabricated from welded preforms.

The other portion of this Contract calls for tool design of an explosive form die for the explosive forming of gore sections for a 396-inch diameter head.

This Final Report summarizes the progress made on this Contract for the period 5 December 1961 through 30 March 1962, and records contractor's findings and conclusions.

II. SCOPE OF WORK

1. Explosively size 2 welded preform bulkheads only, furnished by MSFC. This portion of the contract is an extension from Contract M-F & AE-TLA-R-1 (S2). (Reference Final Report 62B004, dated 10 January 1962.)

2. Fabricate from 1/4 inch 2014-T6 material, and explosively size 1 welded preform.

3. Fabricate from 1/4 inch 2014-T4 material, and explosively size 2 welded preforms.

Contractor's Note: In fabricating conical preforms caution should be taken to pre-radius the metal sections at the weld areas, so that no forming is required in the welded areas.

III. TECHNICAL PROGRESS REPORT SUMMARY

REPORT NO. 1

Ref: Statement of Work, Paragraph I, Reports of Article I, (a), (b) and (c) to Contract NAS 8-2528.

1. In accordance with reference item, Ryan submitted the following Technical Progress Report on subject contract for period 5 December 1961 through 3 January 1962.

2. BC-1304 - GORE DIE TOOL DESIGN

The preliminary tool design on gore die for 396" diameter head was completed on 25 October 1961. Copies of preliminary designs were sent to several reputable casting companies for their comments as to whether or not the design was consistent with good casting practices. Recommendations have been received from casting companies, General Steel, Eddystone, Pa., and the Falk Corporation, Milwaukee, Wisconsin. These recommendations, in the form of marked-up tool designs, are now being evaluated by Ryan Engineering Stress Group.

Preliminary tool design copies were also sent to NASA, who also have forwarded recommendations on tool design.

Upon completion of Ryan's stress analysis, tool design will be brought up to date, taking into consideration all recommendations received. The anticipated completion of contract is 16 February 1962.

3. BC-1305 - Explosive Forming of Welded Preforms

a. .160" 5086 Welded preforms. These MSFC-furnished preforms are a carry-over from contract M-F and AE-TLA-R-1 (S-2).

In this period additional attempts in explosive forming MSFC-furnished preforms failed. The two bulkheads formed fractured adjacent to the circumferential weld, or in the parent material. Bulkhead Number 1 was formed in the as-received condition, and failed at the second shot. In an attempt to overcome this failure, all external welds on bulkhead Number 2 were shaved. Number 2 failed at the second shot.

It is strongly felt that .160", 5086 Al. preforms could satisfactorily be explosively formed, provided the mating edges of preforms are pre-rolled as was the case with the .090", 5086 material. Due to failures, no additional attempt will be made to form the three remaining MSFC-furnished bulkheads.

b. 1/4"2014-T6 preform bulkheads, MSFC-furnished material was received on 11/7/61. On 1 February 1962, preforms had been longitudinally welded and were in the process of having the circumferential mating edges rolled prior to welding. An all-out effort will be made to complete preform in readiness for explosive forming about 13 February 1962.

c. 1/4" 2014 T-4 preform bulkheads, MSFC-furnished material was received on 11/7/61 in the T-6 condition. On 1 February 1962 preforms had been longitudinally welded and solution heat-treated to the T-4 condition and are ready for rolling of circumferential mating edges. Problems in welding 2014 material were encountered, but were overcome. The existing longitudinal and circumferential welds in 2014 preforms are missile X-ray quality.

d. Rolling of the 2014 T-4 and T-6 material into preform shape, as well as rolling of circumferential mating edges, presented some

difficulties. However, through development, these difficulties were overcome. In comparing 2014 to 5086 material, the 5086 material was superior in rolling characteristics.

The next period progress report will report explosive forming results.

REPORT NO. 2.

Ref: Statement of Work, Paragraph I, Reports of Article 1, (a), (b) and (c) to Contract NAS 8-2528.

1. In accordance with reference item, Ryan submitted the following Technical Progress Report on subject contract for period 31 January 1962 through 28 February 1962.

2. BC 1304 - Gore Die Tool Design

Customer Purchase Order Number, M-F & AE-TLA-R-2, was completed approximately 15 February 1962. (See completion Report No. 62B024, Dated February, 1962).

3. BC 1305 - Explosive Forming of Welded Preforms

a. .160", 5086 Welded Preforms, MSFC-furnished pre-forms, a carry-over from contract M-F & AE-TLA-R-1 (S2)

In the period of performance between 31 January 1962 and 28 February 1962, an additional attempt was made to form a third MSFC-furnished preform in the as-received condition. The preform bulkhead fractured adjacent to the circumferential weld, or in the parent material, during the third explosive charge, with the forming approximately only 25% complete.

All indications are that preforms of .160", 5086 Al. could be satisfactorily explosively formed, provided the mating edges of the

preliminary cones are pre-rolled prior to welding, as was the case with the .090" 5086 material. (See Figures I and II).

b. .250", 2014 T6 Aluminum preform bulkheads; preliminary cones have been longitudinally welded and the circumferential mating edges pre-machined prior to edge rolling. Program has been temporarily delayed until the 2014 T4 Aluminum preform bulkhead program is complete, in order to evaluate the feasibility of the continuation of this phase of the task orders, exploring the possibility of forming 2014 Aluminum material in the T6 condition.

c. .250", 2014 T4 Aluminum preform bulkheads; preliminary cones have been longitudinally and circumferentially welded into preform bulkheads ready for explosive forming, with one bulkhead inserted in our 70" hemispherical explosive form die, the attempt being to form the truncated cone into a hemispherical bulkhead. Preform fractured in, or adjacent to, the circumferential welds during the third explosive charge. Circumferential welds were repaired with the truncated cone again being inserted in our 70" hemispherical die, with an attempt made to form further the conical shape into a hemispherical bulkhead. Circumferential welds fractured with a complete burst, producing in the longitudinal welded areas during the third explosive charge.

The second 2014 T4 truncated welded preform bulkhead is now ready for explosive forming, with the explosive forming cycle scheduled for the second week of March. Completion of the 2014 T4 task is estimated at 2 April 1962.

All points of this program are being evaluated at this time. Preliminary evaluation indicates that the rolling radius of the conical pre-rolled mating edges should be increased. This would help to eliminate weld breakage in the circumferential area, although no solution is given at this time for weld breakage in the longitudinal area.

REPORT NO. 3

Ref: Statement of Work, Paragraph I, Reports of Article 1, (a), (b) and (c) to Contract NAS 8-2528.

1. In accordance with reference item, Ryan submits the following Final Technical Progress Report for period 28 February 1962 through 30 March 1962.

2. BC 1305 - Explosive Forming of Welded Preforms

.160" thick, 5086 Welded Preforms, MSFC-furnished. These preforms are a carry-over from Contract M-F & AE-TLA-R-1 (S2). During this period of performance no additional work was done on these preform bulkheads.

3. .250" Thick, 2014-T6 Preform Bulkheads

During this period of performance no additional work was done on these bulkheads. A test was run though on a sample piece of 2014-T6 to determine whether or not the T6 material would withstand the edge rolling required. The specimen was .250" thick, by 3" wide, by 3 feet long. After rolling, shear failure occurred in both edges of the specimen. Existing rolls with 1-1/4" radius were used (See Figures III and IV) showing shear failure.

4. .250" Thick, 2041-T4 Preform Bulkheads

During this period of performance an attempt was made to explosively size bulkhead Number 2. The bulkhead fractured in the circumferential and longitudinal weld areas.

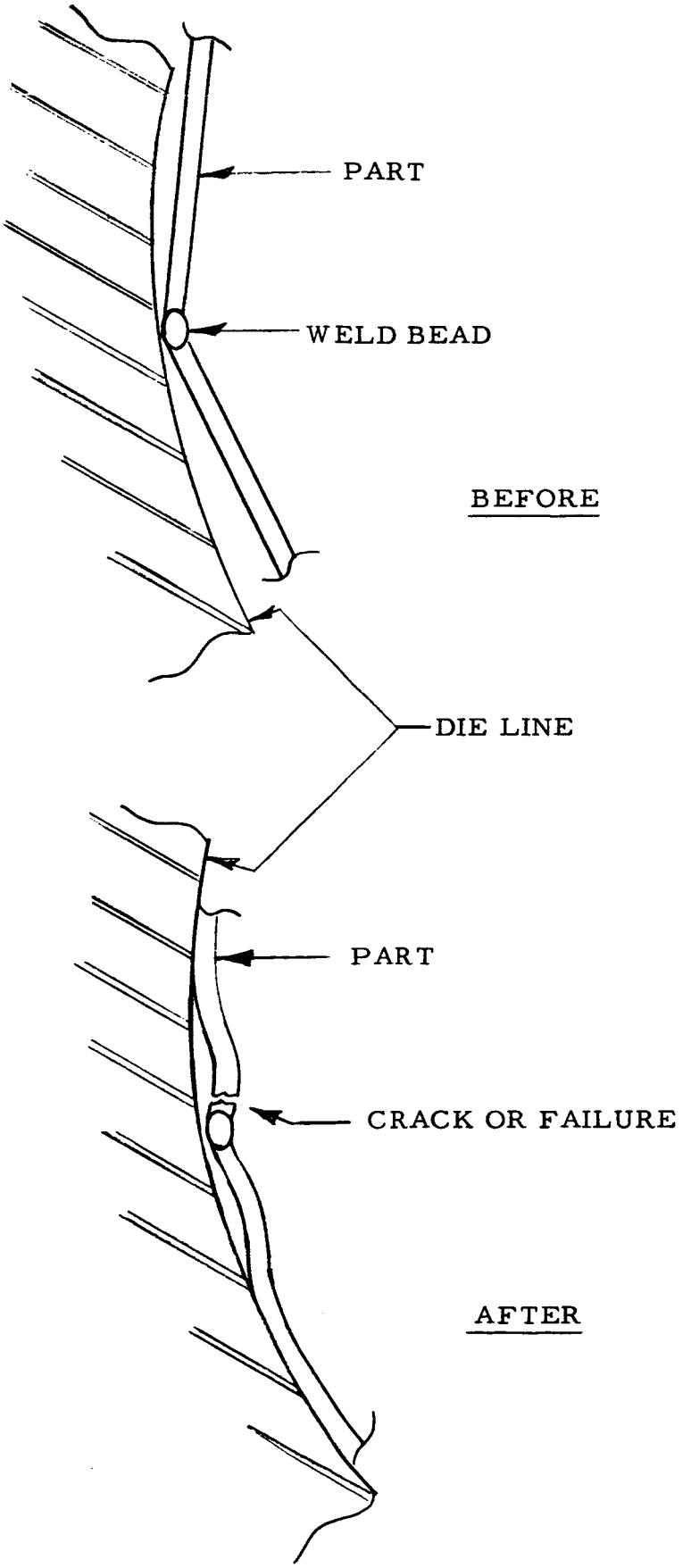


Figure I Cross Section Showing Roof-type Circumferential Configuration and Forming Results

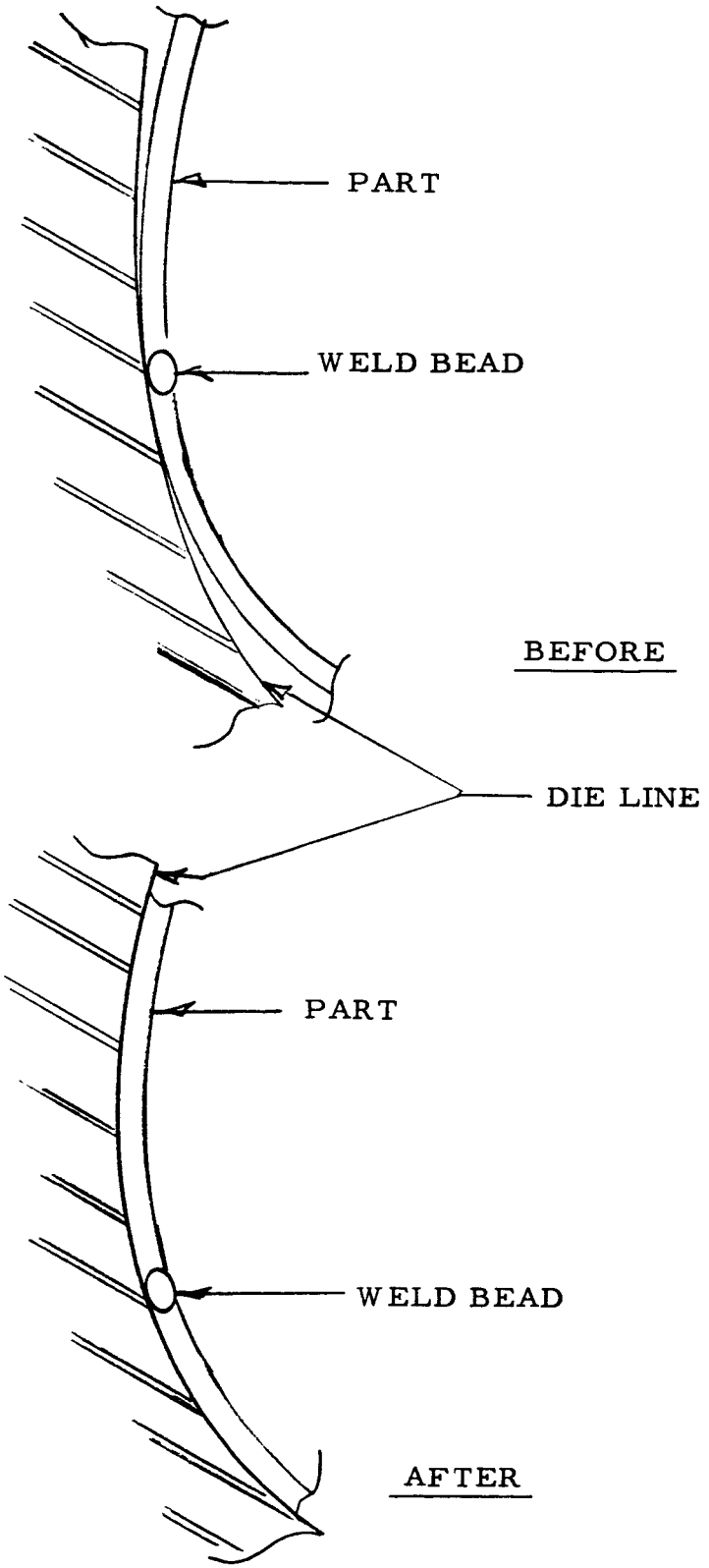


Figure II Cross Section Showing the Preferred Rolled Circumferential Mating Edge Configuration and Forming Results

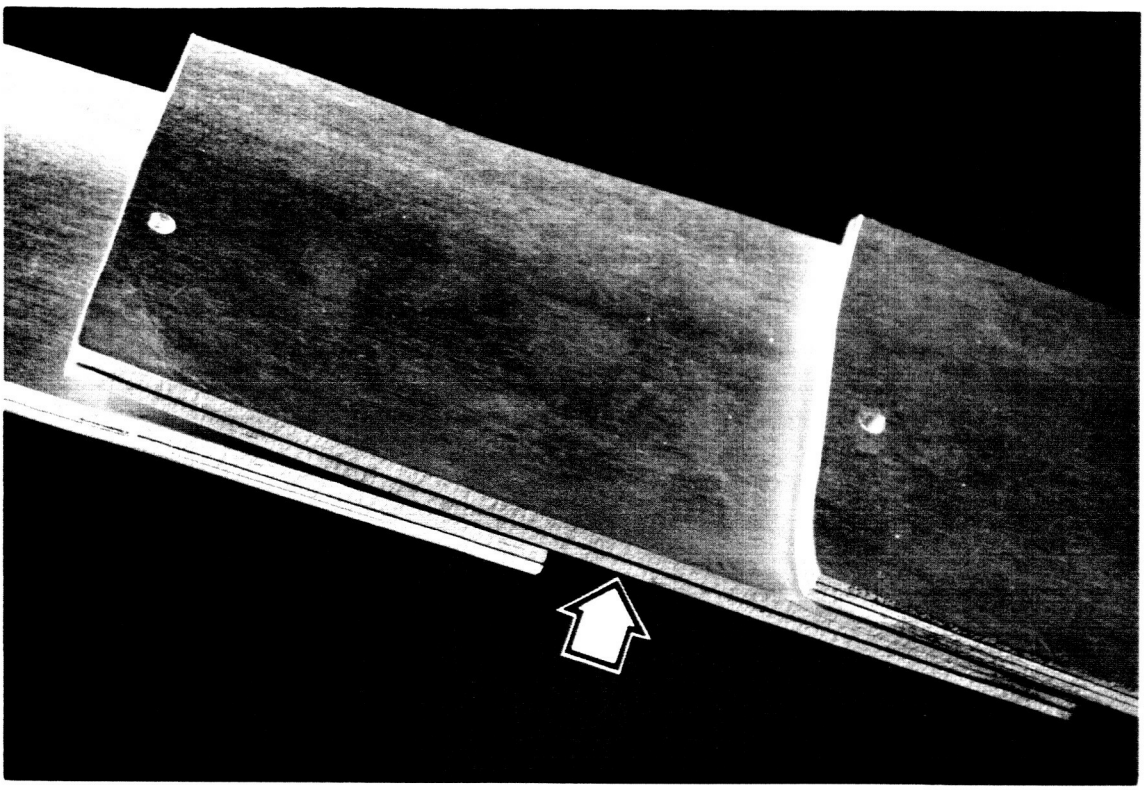


Figure III Edge Rolled Specimen - Sheared Edge Showing Material Separation As Shear Failure on .250" Thick. 2014 T6 as a Result of Edge Rolling to 1-1/4" Radius

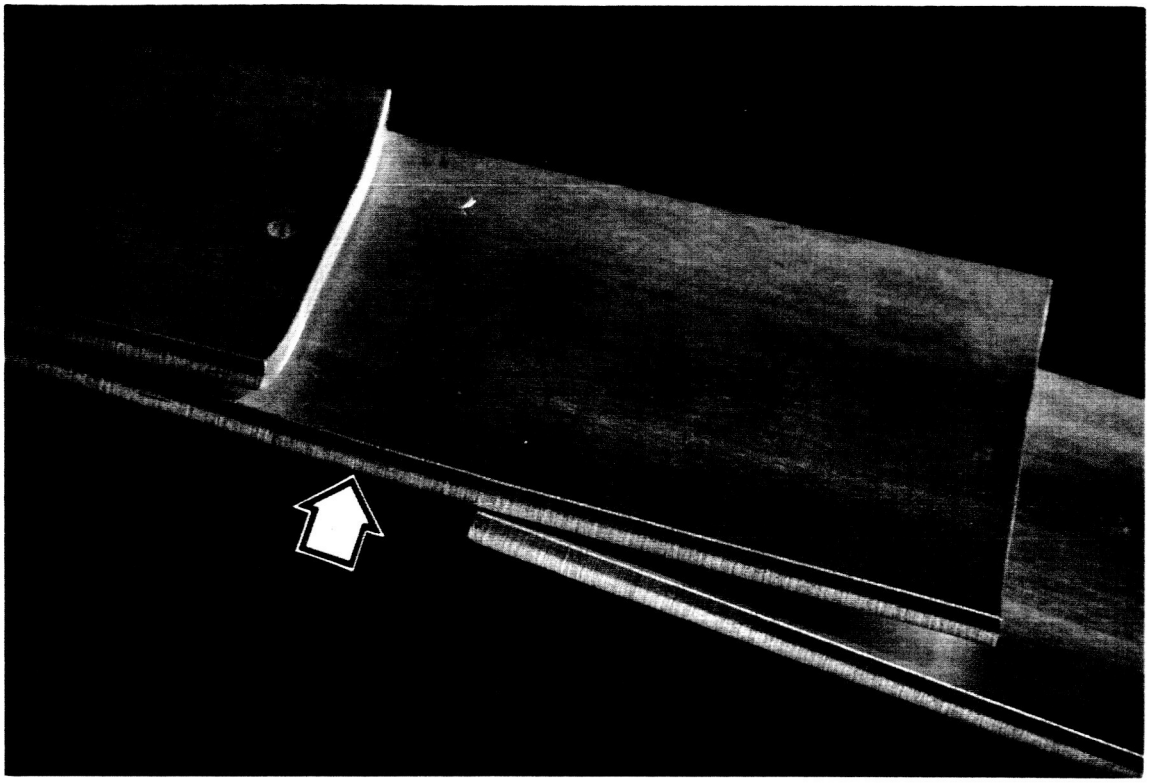


Figure IV Edge Rolled Specimen - Sawed Edge Showing Crease and Localized Separations on .250" Thick, 2014 T6 as a Result of Edge Rolling To 1-1/4" Radius

IV. .160" THICK, 5086-H32 BULKHEADS

CONCLUSIONS

As previously reported, explosive sizing attempts were made on 3 of the 5 bulkheads furnished. All attempts failed.

From past explosive sizing experience, it has been established that a portion of the failures can be attributed to the configuration of the cones at the circumferential mating edges. Successful sizing results on the .090" thick, 5086 bulkheads, have proved that pre-rolling of the circumferential mating edges to a 12 T radius prior to welding eliminates a "roof" type configuration. (See Figures I and II). This allows a minimum of forming to take place in the weld area.

Since the .160" thick, 5086 bulkheads were MSFC-furnished, it was not known under what conditions the furnished bulkheads were welded. Because of this, it cannot be stated whether or not the method of welding contributed in any way to the failures.

V. .250" THICK, 2014-T6 BULKHEADS

CONCLUSIONS

Completion of the 2014-T6 bulkhead was held up pending the explosive forming results of the 2014-T4 bulkheads. Since these results were unsatisfactory, it was decided not to continue with the 2014-T6. A further reason for not continuing was the result obtained from the rolling test made on the T6 specimen, and, as reported in Section II, C, Report No. 3, Item 3, of this report. (See Figure I and II for roof type and rolled edge configuration).

To have continued with the test on the 2014-T6, the following would have had to be accomplished;

1. Fabricate new rolls with a 12T or 3" radius for circumferential edge rolling.

2. Re-develop the cones to accept the 12T radius.

3. Re-design and fabricate new trim and welding tooling to accept 12T radius.

VI. .250" THICK, 2014-T4 BULKHEADS

CONCLUSIONS

Unsuccessful attempts at explosive sizing of welded preforms in this contract can be attributed to the following:

1. Applicable circumferential mating edge rolling radius was not known in time. There was also a lack of rolls to produce the developed radius.

2. Lack of preparation of mating edges prior to rolling to eliminate edge cracks.

3. Inadequate machine tooling for accurately trimming final welded and rolled cones.

4. Inadequate welding tools for both the longitudinal as well as the final circumferential welds.

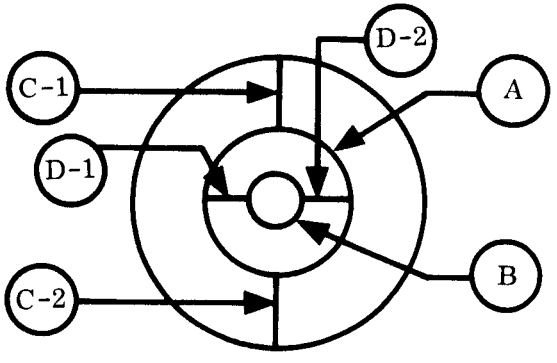
5. Poor fit-up of parts at final welding as a result of the above mentioned inadequacies.

6. The outstanding ability of the longitudinal welds to form to the desired die contour, as compared to the circumferential welds, can be attributed to the fact that they were welded using near-optimum control over all welding parameters. This produced welds with properties as high as could be expected welding this material, and welds which required a minimum of repair welding. It is well known that repair welding of heavy section in 2014 frequently results in disastrous reduction in weld properties. It is noteworthy that of all the longitudinal welds

produced for these bulkheads, only one required repairs and only this one failed catastrophically during explosive forming. The balance formed quite satisfactorily to the die with little or no evidence of defects.

The defects in the other longitudinal welds are not readily explained. There were excessive, locked-up forming stresses in these smaller cones, and these cones were subjected to an apparent reverse bend flexing due to the shape of the part and the location of charges during explosive forming and sizing. Since the cracks in these welds are transverse to the welds, and in the planes of flexing and not longitudinal to the welds, as was dominant in all other weld failures, it is surmised that the reverse flexing was the probable cause of these cracks. The location of these cracks along the weld length also contributes to this reduction, since the forming, matching and fit-up of the abutting edges of all circumferential weld joints presented conditions far short of the optimum, with consequent loss of weld tooling heat control which required excessive manual repair welding. As anticipated, the weld joints were structurally weakened to the point of failure at extremely low levels of stress and deformation. With optimum conditions at the weld joint as regards part preparation, fit-up tooling, these welds should respond equally as well as the longitudinal welds to explosive sizing and forming.

All tooling used was a carry-over from the original 70" diameter bulkhead contract. This tooling, slightly altered to accommodate the .250" thick, 2014 material, proved to be inadequate to maintain the control necessary to provide a welded preform bulkhead suitable for explosive sizing.



V - Visual
D - Dye Penetrant
X - X-Ray

Radiographic Spec.
ABMA-PD-R-27A

	WELD QUALITY BEFORE FORMING			WELD QUALITY AFTER FORMING	
WELD	INSP. METHOD	REPAIR	QUALITY	INSP. METHOD	QUALITY AND COMMENTS
PREFORM #1					
A	V, D, X	Extensive	Class IV Border Line	V	Fractured and cracked longitudinally
B	V, D, X	Extensive	Class IV Border Line	V	Sound
C-1	V, D, X	2 Spots	A-1 Class I	V	Fractured longitudinally, through repairs
C-2	V, D, X	None	A-1 Class I	V, X	A-1, Class I
D-1	V, D, X	None	A-1 Class I	V, X	Two (2) short transverse cracks
D-2	V, D, X	None	A-1 Class I	V, X	Two (2) short transverse cracks
PREFORM #2					
A	V, D, X	Extensive	Class IV Border Line	V	Fractured and cracked longitudinally
B	V, D, X	Extensive	Class IV Border Line	V	Sound - Border line
C-1	V, D, X	None	A-1 Class I	V	Sound
C-2	V, D, X	None	A-1 Class I	V	Sound
D-1	V, D, X	None	A-1 Class I	V	Two (2) short transverse cracks
D-2	V, D, X	None	A-1 Class I	V	Sound

Table I Weld Inspection Results .250" 2014-T4 Bulkhead

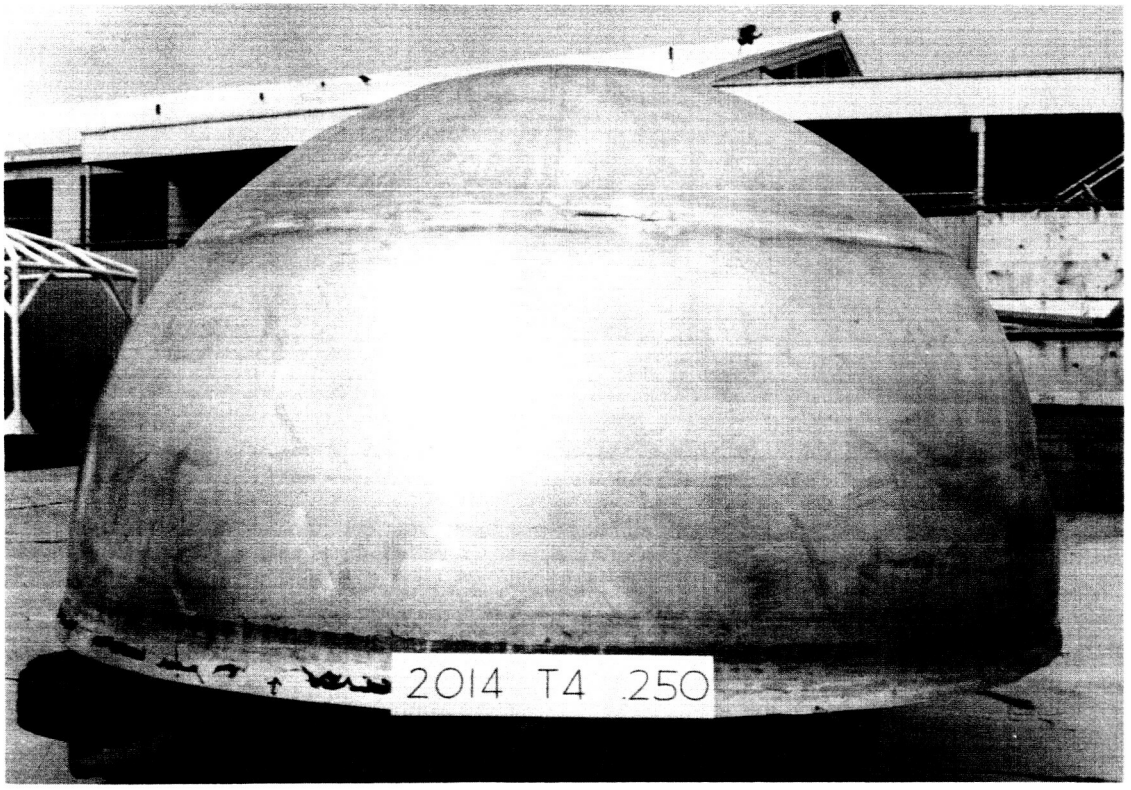


Figure V Bulkhead No. 1 - Showing Circumferential Failure and Position of Sound Longitudinal Weld. Approximately 85% Formed.

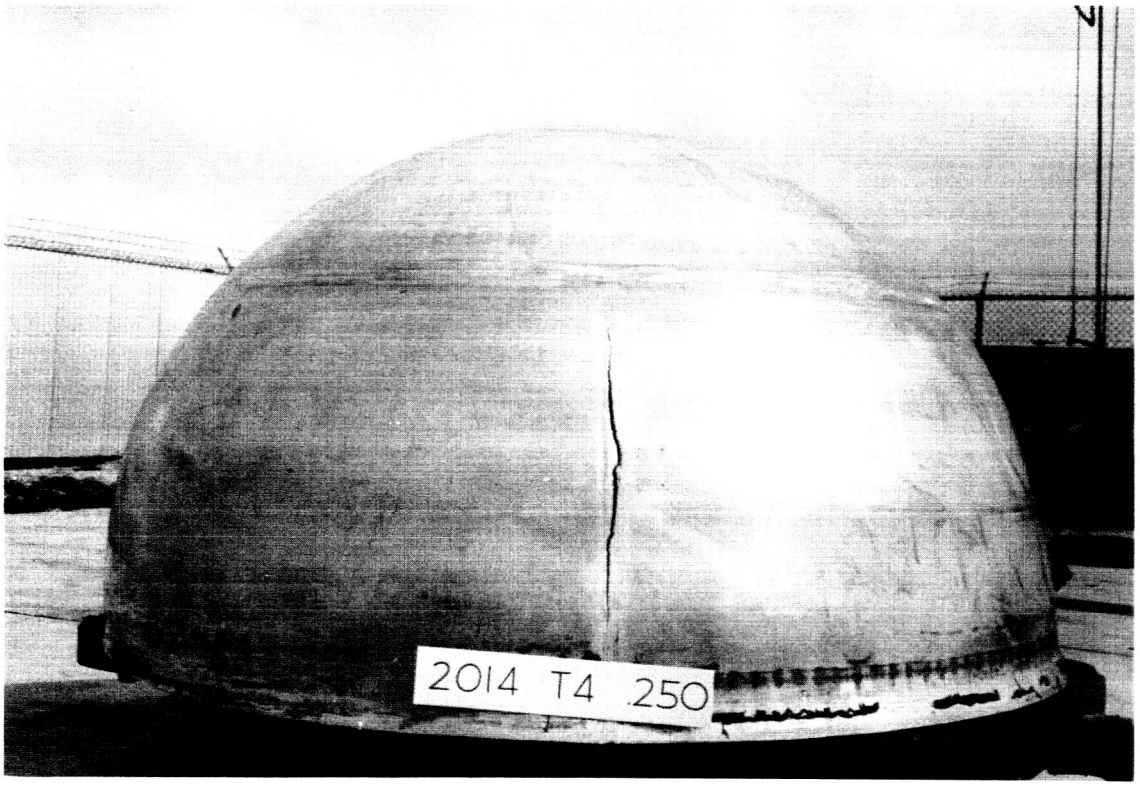


Figure VI Bulkhead No. 1 (Rotated 90°) - Showing Longitudinal Weld Failure. Not Visible are Intermittent Longitudinal Cracks Throughout Circumferential Weld.

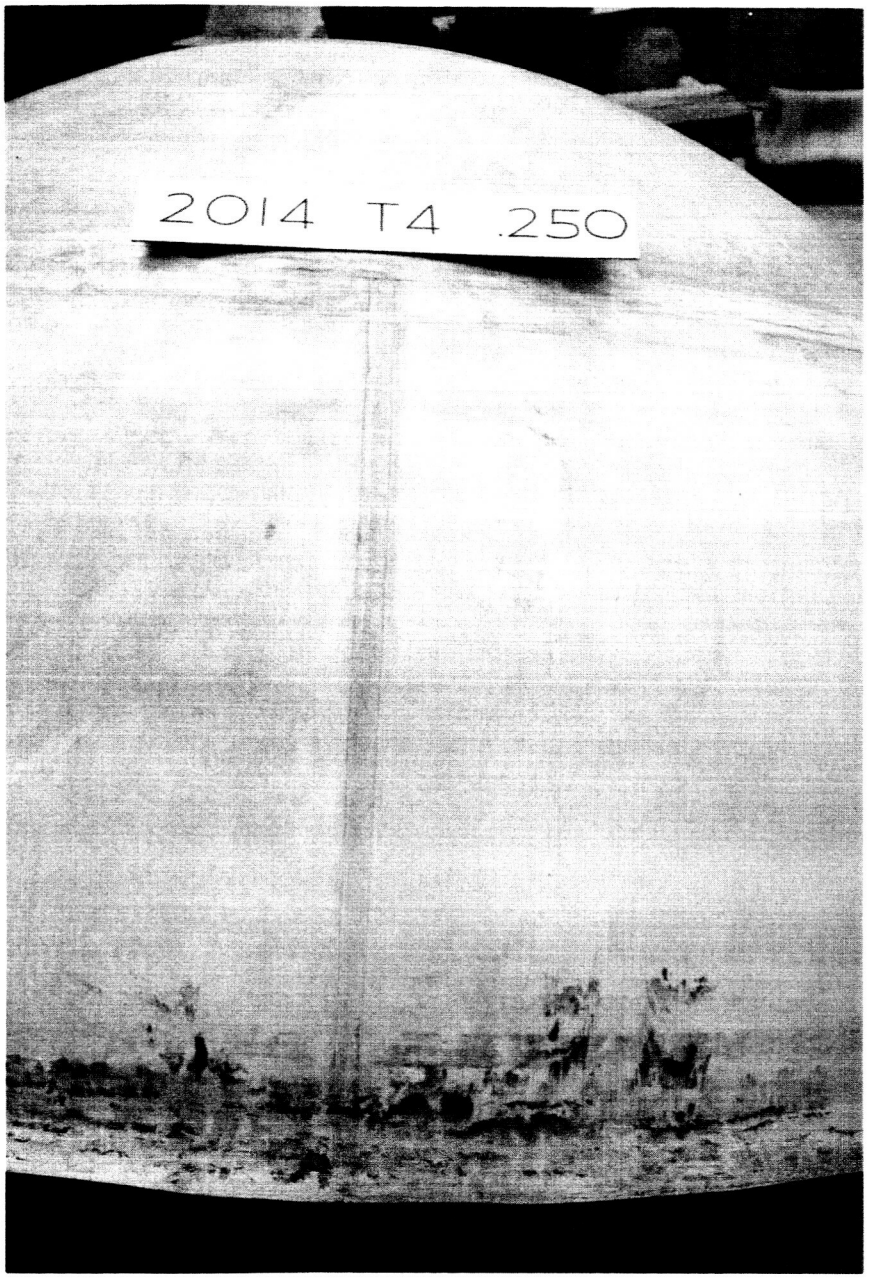


Figure VII Bulkhead No. 1 - Opposite Side of Figure VI, Showing Sound Longitudinal Weld

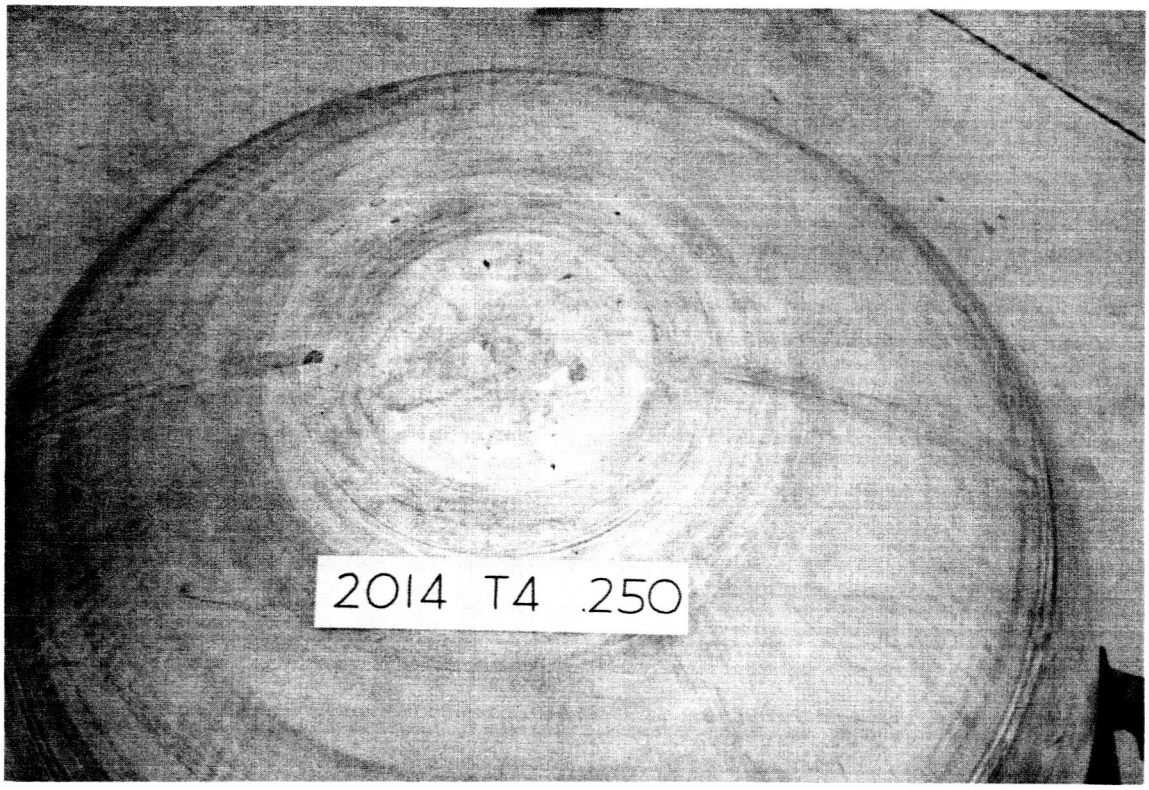


Figure VIII Bulkhead No. 1 - Top View Showing Sound Longitudinal and Circumferential Welds

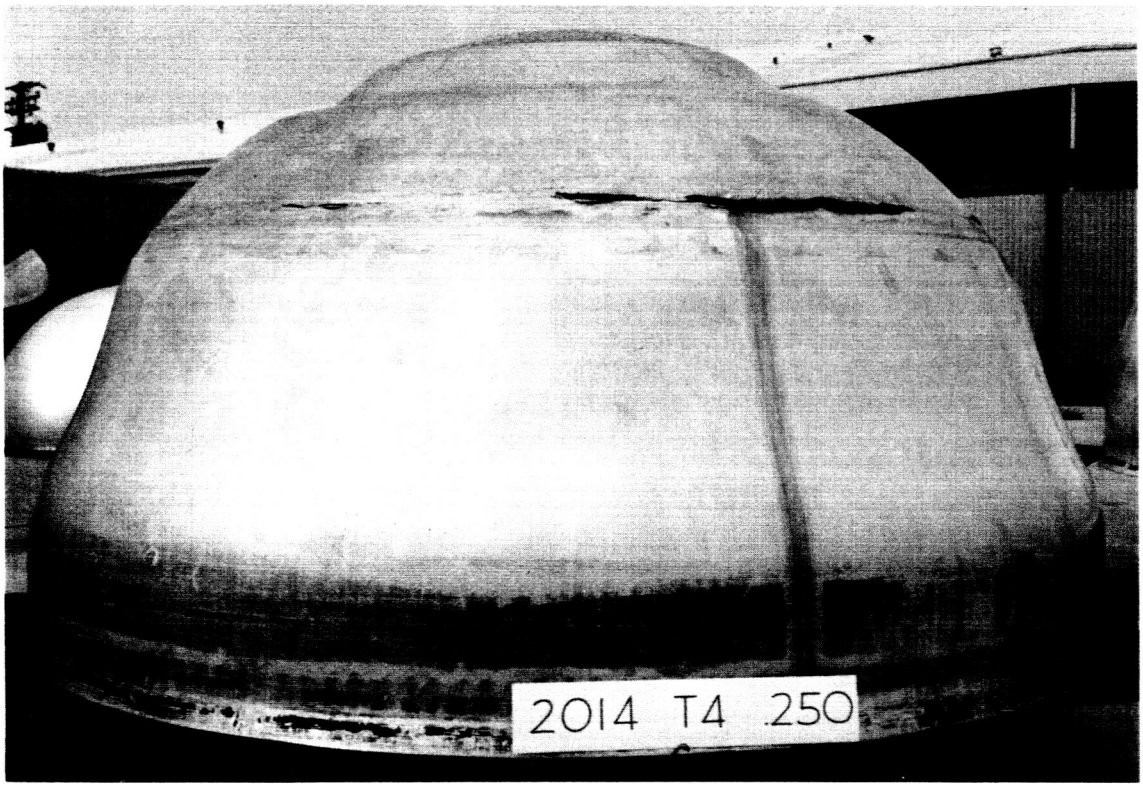


Figure IX Bulkhead No. 2 - Showing Circumferential Failure and Sound Longitudinal Weld. Approximately 65% Formed.

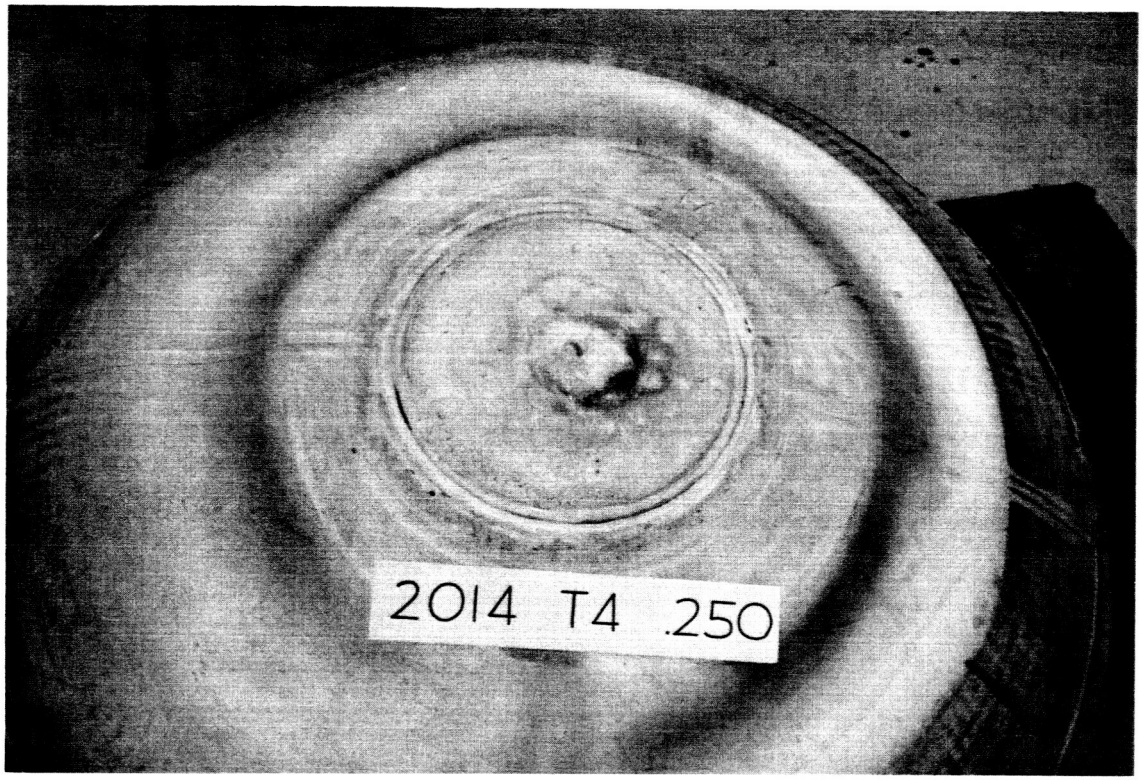


Figure X Bulkhead No. 2 - Top View Showing Sound Longitudinal and Circumferential Welds

VII. FINDINGS

To achieve successful welds essential in fabricating bulkheads of this type it was found that along with accurate rolling, trimming, and cleanliness of material, the welding tooling for both the longitudinal and circumferential welds must be the best possible. Failure of the welds on the 2014 bulkheads was partially caused by inadequate welding tooling. It was also found that 2014 is sensitive to welding conditions as compared to other types of aluminum.

The success in rolling of the circumferential mating edges depends upon the thickness of the material to be rolled. Through development, the best suited radius was found to be 12T, or 12 times the thickness of the material to be used.

In the rolling process it was found that the 2014-T4 and T6 material was notch and crack sensitive. Correct edge preparation prior to all rolling is mandatory.

Rolling of individual cones has to be accurately controlled to eliminate stress build-up in the longitudinal weld joint. Gradual accumulation of stresses at all weld joints (as a result of poor fit-up of parts) on a completely welded bulkhead presents a catastrophic condition when explosive sizing takes place. It is imperative that all parts, when finally welded, should be in a relaxed state.

In conclusion it can be said that bulkheads made of .160" thick, 5086, .250" thick 2014-T4 and T-6 may be successfully explosively sized provided the following conditions are adhered to:

a. Correct development of cone flat pattern.

b. Controlled rolling and trimming of cones to produce a stress-free longitudinal weld joint.

c. Correct edge preparation prior to any rolling.

d. Cleanliness of material, particularly at all weld joints, prior to welding.

e. Controlled rolling of all circumferential mating edges.

f. Good tooling to accurately machine trim the rolled circumferential mating edges.

g. Good weld tooling to accurately locate and hold part as well as good back-up.

h. Good welding machine and welding technique.